

# Factors controlling N<sub>2</sub>O and CH<sub>4</sub> fluxes in mixed broad-leaved/Korean pine forest of Changbai Mountain, China<sup>1</sup>

Xu Hui(徐慧) Chen Guanxiong(陈冠雄) Huang Guohong(黄国宏)

Han Shijie(韩士杰) Zhang Xiujun(张秀君)

*Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110015, P.R. China*

**Abstract** Using the closed chamber technique, the *in situ* measurements of N<sub>2</sub>O and CH<sub>4</sub> fluxes was conducted in a broad-leaved Korean pine mixed forest ecosystem in Changbai Mountain, China, from June 1994 to October 1995. The relationships between fluxes (N<sub>2</sub>O and CH<sub>4</sub>) and some major environmental factors (temperature, soil water content and soil available nitrogen) were studied. A significant positive correlation between N<sub>2</sub>O emission and air/soil temperature was observed, but no significant correlation was found between N<sub>2</sub>O emission and soil water content (SWC). This result showed that temperature was an important controlling factor of N<sub>2</sub>O flux. There was a significant correlation between CH<sub>4</sub> uptake and SWC, but no significant correlation was found between CH<sub>4</sub> uptake and temperature. This suggested SWC was an important factor controlling CH<sub>4</sub> uptake. The very significant negative correlation between logarithmic N<sub>2</sub>O flux and soil nitrate concentration, significant negative correlation between CH<sub>4</sub> flux and soil ammonium content were also found.

**Key words:** Broad-leaved/Korean pine forest, N<sub>2</sub>O, CH<sub>4</sub>, Flux, Environmental factors

## Introduction

The increasing greenhouse gas concentrations have received much attention. Two of these gases that scientists are very concerned about are N<sub>2</sub>O and CH<sub>4</sub>, because of their rapid increase and their important chemistry in the atmosphere (Bouwman 1990). The molecule global warming potential of N<sub>2</sub>O and CH<sub>4</sub> are about 58 and 206 times than that of CO<sub>2</sub>. In addition, atmospheric concentrations of N<sub>2</sub>O and CH<sub>4</sub> are increasing at annual rates of 0.25% and 0.9% respectively (Houghton *et al.* 1992). Forest ecosystem has been known as an important terrestrial ecosystem at the aspect of study in source and sink of greenhouse gases. On the one hand, forest ecosystem is an important source of N<sub>2</sub>O. From the estimate of known global sources and sinks of N<sub>2</sub>O made by IPCC (1992), the total natural source of N<sub>2</sub>O was 4.15~10.3 Tg·a<sup>-1</sup>, and the emission from tropical wet forests and temperate forests were 2.2~3.7 and 0.05~2.2 Tg·a<sup>-1</sup>, respectively. Kreileman and Bouwman (1994) also estimated that the N<sub>2</sub>O emissions from closed tropical forests, open tropical forests and temperate forests were 2.3, 1.0 and 0.5 Tg·a<sup>-1</sup> respectively. In the meantime, their estimation of total amount of N<sub>2</sub>O emission from terrestrial surface was only 6.6 Tg·a<sup>-1</sup>. Therefore, from the above

data, forest ecosystem can be regarded as the biggest contributor to the atmospheric N<sub>2</sub>O among the terrestrial ecosystems. On the other hand, forest ecosystem is an important sink of atmospheric CH<sub>4</sub>. Soils can consume about 30~40 Tg CH<sub>4</sub> per year, especially the forest soil (King & Schnell 1994).

The area of Chinese forest is 13370×10<sup>4</sup> hm<sup>2</sup>, the percentage of forest area in terrestrial area is 13.92%. The forest ecosystem is an important component of Chinese terrestrial ecosystems. However, till now, there is very little data reported on N<sub>2</sub>O and CH<sub>4</sub> fluxes from forest ecosystem in China. In this paper, *in situ* field measurements of N<sub>2</sub>O and CH<sub>4</sub> fluxes from a mixed broad-leaved/Korean pine forest in Changbai Mountain were conducted. The effects of some environmental factors (temperature, soil water content, and available nitrogen) on fluxes of N<sub>2</sub>O and CH<sub>4</sub> were studied.

## Methods

Natural reserve in Changbai Mountain is the region of famous original forests, in which *Pinus koraiensis* is the main stand, and biological resources are rich. Experimental site is located in a mixed broad-leaved/Korean pine forest (42°24' N, 128°28' E), which annual mean temperature is 3°C, and annual mean precipitation is 700-800 mm. The soil of the forest is mountain dark brown forest soil.

Fluxes were measured during the period between June 1994 and October 1995 (except wintertime,

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details on sampling date are given in Fig.1). The closed chamber technique was used. PVC boxes (upturned bucket), 24 cm in height and 10 cm in diameter, were inserted into soil at 4-cm depth. 5-7 boxes of replicate were distributed randomly within an area of 10 m×10 m. Gas samples in the boxes were taken by plastic syringes at 0 and 1 hour after the inserting of boxes. Samples were stored in the gas storing bags (Institute of Chemistry Engineering, Dalian, China), and then were transported to laboratory and analyzed for the N<sub>2</sub>O and CH<sub>4</sub> concentrations.

N<sub>2</sub>O were measured with Shimadzu GC-14A, electron capture detector (<sup>63</sup>Ni) at 300 °C, Porapak Q column at 60°C, 1 ml gas sample in sample loop was injected automatically into column and with back-flowing of water in sample. CH<sub>4</sub> was quantified with a flame ionization detector at 150 °C, 5Å molecular sieve column at 60 °C, 4 mL gas sample in sample loop was injected into column.

Fluxes of gases ( $F$ ) are calculated from the change in concentration ( $\Delta C$ ) over a period of time ( $\Delta t$ ).

$$F = \frac{\rho \times V \times \Delta C}{A \times \Delta t}$$

Where  $V$  is the volume of the chamber above the enclosed soil with surface area ( $A$ ).  $\rho$  is the density of gas.

Soil water content was measured with fresh soil from 0-10 cm depth sampled immediately after measurement of fluxes finished and expressed with percentage of soil field capacity. Soil temperature was measured at the soil depth of 5-8 cm. Soil exchangeable NO<sub>3</sub><sup>-</sup> and NH<sub>4</sub><sup>+</sup> were determined by MgO-Devarda alloy method.

The relationships between gases' fluxes and environmental factors were statistically analyzed with SPSS 6.0 software.

## Results and discussion

Recent studies showed that the environmental factors, such as temperature, soil aeration, soil water content and available nitrogen, pH, etc, may have important effect on N<sub>2</sub>O and CH<sub>4</sub> fluxes from forest ecosystem. However, no *in situ* measurement has been reported in China. In this paper, relationships between some environmental factors and fluxes from the *in situ* measurements in a mixed broad-leaved/Korean pine forest in China were described.

### Temperature and N<sub>2</sub>O flux

The seasonal variation of air temperature, soil temperature and N<sub>2</sub>O flux in the mixed broad-leaved/Korean pine forest were shown in Fig. 1. Statistical positive correlations between N<sub>2</sub>O flux and air/soil

temperature were found. These relationships were described as following equations (1) and (2).

$$F(\text{N}_2\text{O}) = 7.4989 \times T_a - 16.854 \quad (r=0.6011, n=15, P<0.05) \quad (1)$$

$$F(\text{N}_2\text{O}) = 4.9592 \times T_s - 8.538 \quad (r=0.5884, n=15, P<0.05) \quad (2)$$

Where  $F(\text{N}_2\text{O})$  is the N<sub>2</sub>O flux ( $\mu\text{g} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$ ),  $T_a$  is the air temperature,  $T_s$  is the soil temperature.

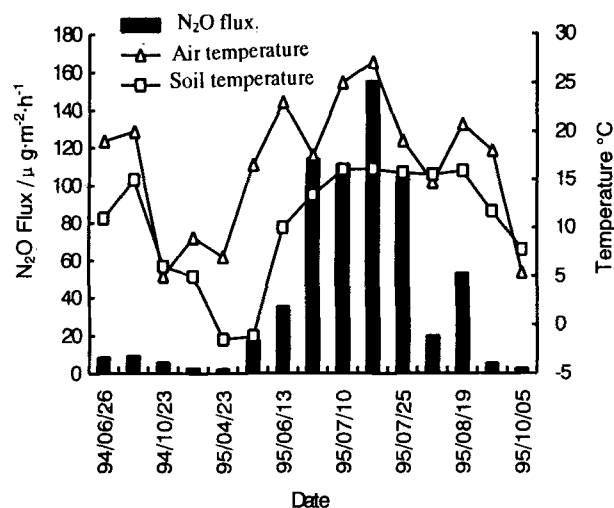


Fig. 1. N<sub>2</sub>O flux and temperature of mixed broad-leaved/Korean pine forest

Within the period of observation, large ranges of seasonal fluctuation of air and soil temperature were found. The air temperature varied from 4 °C to 27 °C, and the soil temperature varied from -3 °C to 17 °C. The correlation between N<sub>2</sub>O flux and temperature indicates that the temperature variation is one of main controlling factors of seasonal N<sub>2</sub>O variation. In general, the nitrification and denitrification are the main N<sub>2</sub>O production processes in the soil. The incubation study showed that  $Q_{10}$  value of nitrification and denitrification of the soil were 2.80 (6-28 °C) and 2.78 (6-28 °C), respectively (in: Xu Hui's doctoral dissertation). A  $Q_{10}$  value greater than 2 indicated a significant effect of temperature on this biological process. Therefore, the effect of temperature on N<sub>2</sub>O flux is the result of temperature's effect on nitrification and denitrification.

### Temperature and CH<sub>4</sub> flux

No significant correlation was found between the air/soil temperature and CH<sub>4</sub> flux in this study. Due to the limitation of fieldwork condition, the *in situ* experiments were only conducted in spring, summer

and autumn. The result of incubation experiment showed that  $Q_{10}$  value of  $CH_4$  oxidation in this mountain dark brown forest soil was only 1.20 (6-28 °C). A  $Q_{10}$  value smaller than 2 indicates the weak effect of temperature on the biological process. However, Other studies showed the significant influence of temperature on  $CH_4$  oxidation at low temperature. Castro (1995) reported that soil temperature was an important controller of  $CH_4$  consumption at temperatures between -5 °C and 10 °C, but had no effect on  $CH_4$  consumption at temperature between 10 and 20 °C. King and Adamsen (1992) showed also that temperature increases from -2 °C to 2 °C significantly increased  $CH_4$  consumption by soil cores from a mixed deciduous-coniferous forest in Maine, while temperature increases from 2 °C to 30 °C had little effect on  $CH_4$  consumption. Collectively, results from these studies support the idea that temperature is an important controller of  $CH_4$  consumption by forest soils in winter and during the transition from spring to summer and fall to winter. This suggests that future changes in soil temperature above our normal high of 20°C are not likely to increase the strength of this  $CH_4$  sink.

#### Soil Moisture and $N_2O$ Flux

The soil water content was varied between 58.64%~121.23% FC in the period of observation. No significant correlation was found between soil water content and  $N_2O$  flux in the mixed broad-leaved/ Korean pine forest. This result indicated that soil water content was not the limiting factor on  $N_2O$  flux in this period. Water is necessary for microbial activity. Increasing water content can, up to a point, increase the rate of mineralization and the availability of nutrients. Linn and Doran (1984) illustrated the effect of soil water on soil processes through its influence on aeration and microbial activity. With increasing water content up to 60% WFPS, nitrification increased with enhanced microbial activity. An increase in WFPS from 60% to 100% gives a marked reduction in nitrification, some reduction in microbial activity and an increase in denitrification rate as conditions become more anaerobic. The soil water content, therefore in this study, met the need for either nitrification or denitrification during the measuring period.

#### Soil moisture and $CH_4$ flux

The relationship between  $CH_4$  flux and soil water content in the mixed broad-leaved/Korean pine forest was found to be a negatively correlation (Fig.2). This correlation was presented as the equation (3):

$$F(CH_4) = 112.8277 \times SWC - 139.592$$

$$(r = 0.7779, n = 7, P < 0.05) \quad (3)$$

Where  $F(CH_4)$  is the  $CH_4$  flux ( $\mu g \cdot m^{-2} \cdot h^{-1}$ ), SWC is the soil water content.

This pattern is consistent with the results from other field studies of Koschorreck & Conrad (1993), Keller & Reinert (1994) and Castro *et al.* (1995). Koschorreck & Conrad (1993) reported that  $CH_4$  (expressed as  $CH_4-C$ ) consumption by forest soils in Germany decreased from 0.03 to 0.006  $mg \cdot m^{-2} \cdot h^{-1}$  as soil moisture increased from about 40% to 90% water-holding capacity. Castro (1994) reported that soil moisture exerted strong control on  $CH_4$  consumption over a range of 60% to 100% WFPS,  $CH_4$  consumption decreased linearly from 0.1 to 0  $mg \cdot m^{-2} \cdot h^{-1}$ . Potential explanations for the moisture-induced reduction of  $CH_4$  consumption include: (1) a shift in the net flux towards more  $CH_4$  production at high soil moisture, (2) physiological stress on the microbial communities that oxidize  $CH_4$  at high soil moisture, and (3) alternations in soil gas transport rates at high soil moisture. Results from our incubation experiments showed that very little  $CH_4$  was produced in this soil under wet conditions (in: Xu Hui's doctoral dissertation). In addition, soil microbial communities did not appear to be severely stressed by exposure to high soil moisture. Therefore, the reduced  $CH_4$  consumption is likely to be caused by slower transport of  $CH_4$  from the atmosphere to the subsurface zone of consumption at high soil moisture because  $CH_4$  transport is 10 000 times slower in water than in air.

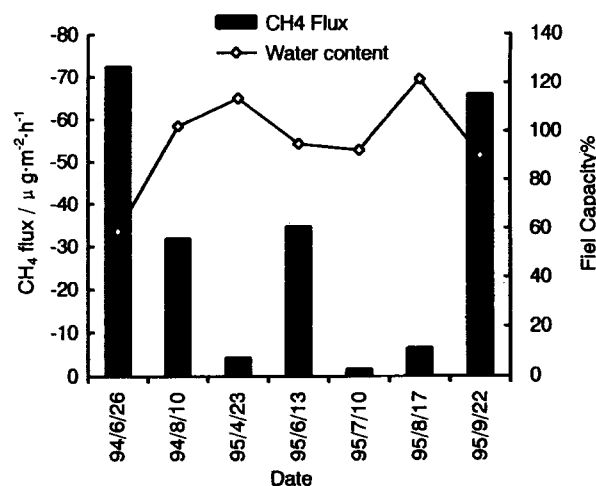


Fig. 2.  $CH_4$  flux and water content of mixed broad-leaved/Korean pine forest

#### Soil available $NO_3^-$ and $N_2O$ Flux

Availability of mineral nitrogen ( $NH_4^+$  and  $NO_3^-$ ) to bacteria is an important controller for the microbial processes that produce  $N_2O$ . The soil  $NO_3^-$  content of

soil at 0-10cm depth in the mixed broad-leaved/ Korean pine forest varied between 2.5-33.5 mg N · kg<sup>-1</sup> dry soil (Fig.3). A correlation which was found between soil available nitrate concentration and N<sub>2</sub>O flux was presented as equation (4).

$$\text{Log } F(\text{N}_2\text{O}) = -6.6704 \times [\text{NO}_3^- - \text{N}] + 5.1969$$

$$(r = 0.9612, n = 5, P < 0.01) \quad (4)$$

Where  $[\text{NO}_3^- - \text{N}]$  is concentration of soil available nitrate(N) (mg · kg<sup>-1</sup> dry soil), Log  $F(\text{N}_2\text{O})$  is logarithmic value of N<sub>2</sub>O flux.

Nitrification and denitrification were known as two main N<sub>2</sub>O production processes in the terrestrial ecosystem. NO<sub>3</sub><sup>-</sup> is one of the products of nitrification, as well as a substrate of denitrification. In general, high NO<sub>3</sub><sup>-</sup> concentration can increase the rate of denitrification and the N<sub>2</sub>O/N<sub>2</sub> ratio in the product, but inhibit the rate of nitrification. The negative correlation between soil NO<sub>3</sub><sup>-</sup> content and N<sub>2</sub>O flux found in this study can be explained by the inhibition of NO<sub>3</sub><sup>-</sup> on nitrification, which is the dominant process of N<sub>2</sub>O production in this soil.

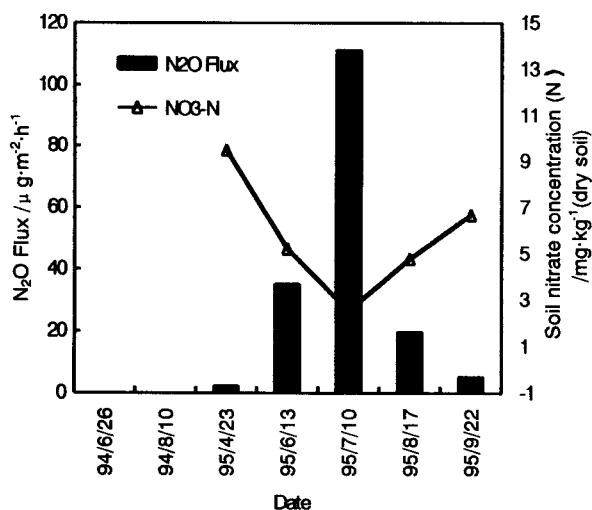


Fig. 3. Soil nitrate concentration and N<sub>2</sub>O flux of mixed broad-leaved Korean pine forest

#### Soil available NH<sub>4</sub><sup>+</sup> and CH<sub>4</sub> Flux

The soil NH<sub>4</sub><sup>+</sup> content (0~10-cm depth) varied between 23.1~43.1 mgN · kg<sup>-1</sup> dry soil. A positive correlation (equation (5)) between CH<sub>4</sub> flux and soil NH<sub>4</sub><sup>+</sup> content was found (Fig.4).

$$F(\text{CH}_4) = 1.7649 \times [\text{NH}_4^+] - 68.9797$$

$$(r = 0.8918, n = 7, P < 0.05) \quad (5)$$

Where  $F(\text{CH}_4)$  is the CH<sub>4</sub> flux (μg · m<sup>-2</sup> · h<sup>-1</sup>),  $[\text{NH}_4^+]$  is the soil NH<sub>4</sub><sup>+</sup> content (mgN · kg<sup>-1</sup> dry soil).

The nitrogen fertilization may decrease the rate at which temperate forest soils uptake CH<sub>4</sub> from the atmosphere was first reported by Steudler *et al.* (1989). Mosier (1991) suggested that high N turnover, whether native or due to fertilization, suppressed CH<sub>4</sub> uptake. Castro *et al.* (1995) gave a further explanation: changes in the soil nitrogen cycle following fertilization may induce shifts in the relative activities of the microbial populations that oxidize atmospheric methane from those dominated by methanotrophs in fertilized soils to those dominated by ammonium oxidizers in fertilized soils. Ammonium oxidizers have 100 to 10,000 times lower CH<sub>4</sub> oxidation rates than that of the methanotrophs. Another hypothesis was described by Megraw & Knowles (1989). The methane-dependent nitrate production (methanotrophic nitrification) existed in soil. The increased CH<sub>4</sub> concentration enhanced the oxidation of NH<sub>4</sub><sup>+</sup> by methanotrophs, but nitrite, the product of NH<sub>4</sub><sup>+</sup> oxidation, is the inhibitor of CH<sub>4</sub> oxidation. Methanotrophic nitrification, although inhibited by increasing CH<sub>4</sub> concentrations, is dependent on CH<sub>4</sub>. In addition, Xu Hui *et al.* (1999) reported the statistical correlations between *in situ* N<sub>2</sub>O emission rate and CH<sub>4</sub> consumption rate of different forest soils. Therefore, CH<sub>4</sub> is likely to be an important factor in the regulation of nitrification and N<sub>2</sub>O production and, more generally, in the N cycle in natural environments.

An important challenge is to predict how global changes, such as climate, land use, and atmospheric nitrogen deposition, will affect the exchange of greenhouse gases between the atmosphere and biosphere. From the data of current studies, increased nitrogen deposition may lower the ability of soil to consume atmospheric CH<sub>4</sub>.

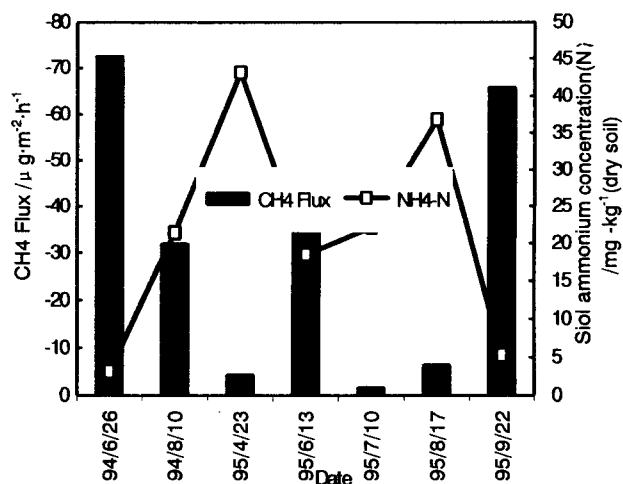


Fig. 4. Soil ammonium concentration and CH<sub>4</sub> flux of mixed broad-leaved/Korean pine forest

## Conclusion

The simultaneous *in situ* measurements of  $N_2O$  and  $CH_4$  fluxes and the environmental factors allowed the discussion of which may be the controlling factors. In this study, a significant positive correlation between  $N_2O$  emission and temperature, and a significant correlation between  $CH_4$  uptake and soil moisture indicated that temperature and soil moisture were the controlling factor for  $N_2O$  flux and  $CH_4$  flux, respectively. The results of correlation between soil nitrate content and  $N_2O$  flux, and correlation between soil ammonium content and  $CH_4$  flux indicated that soil nitrate and ammonium concentrations were also the important influencing factor for  $N_2O$  flux and  $CH_4$  flux.

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